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JC535 U.S. PTO 10/16/97

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NEW UTILITY PATENT APPLICATION TRANSMITTAL
(to be used for new applications only)

Attorney Docket Number	63.666.90245
First Named Inventor	James F. Greenleaf
Total Pages in the Submission	20

APPLICATION ELEMENTS

Notice: Checklist items mentioned under Application Elements section construct a new utility patent application. Please refer to MPEP Sections 506, 601. (37 C.F.R. 1.77, 1.53, 35 USC 111, 112, 113) for detailed explanation regarding completeness of an original patent application.

ACCOMPANYING APPLICATION PARTS

1. [X] Fee transmittal Form (prescribed filing fees(s))
2. Specification
   - [X] Title of the Invention
   - [ ] Cross References to Related Applications (if applicable)
   - [ ] Statement Regarding Federally-sponsored Research/Development *(if applicable)*
   - [ ] Reference to Microfiche Appendix *(if applicable)*
   - [X] Background of the Invention
   - [X] Brief Summary of the Invention
   - [X] Brief Description of the Drawings *(if drawings filed)*
   - [X] Detailed Description
   - [X] Claim or Claims
   - [X] Abstract of the Disclosure
3. [X] Drawings *(when necessary as prescribed by 35 USC 113)*
4. [X] Executed Declaration
5. Genetic Sequence Submission *(if applicable, all must be included)*
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Firm or Individual Name	Barry E. Sammons
Signature	Barry E. Sammons
Date	10/16/97

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Application Number			Class			Independent Claims	
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	Filing Date		Foreign Filing License?			Drawing Sheets	
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FEE TRANSMITTAL

TOTAL AMOUNT OF PAYMENT	$ 830.00

Complete if Known	
Application Number	
Filing Date	
First Named Inventor	James E. Greenleaf
Group Art Unit	
Examiner Name	
Attorney Docket Number	630666.90245

METHOD OF PAYMENT (check one)

1. [X] The Commissioner is hereby authorized to charge indicated fees and credit any over payments to:

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FEE CALCULATION (fees effective 10/01/97)

1. FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	790	201	395	Utility filing fee	790.00
106	330	206	165	Design filing fee	
107	540	207	270	Plant filing fee	
108	790	208	395	Reissue filing fee	
114	150	214	75	Provisional filing fee	

SUBTOTAL (1) ($)790.00

2. CLAIMS

		Extra		Fee from below		Fee Paid
Total Claims	16	-20=	0	X 22.00	=	0.00
Independent Claims	3	-3=	0	X 82.00	=	0.00
Multiple Dependent Claims				270.00	=	0.00

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	22	203	11	Claims in excess of 20
102	82	202	41	Independent claims in excess of 3
104	270	204	135	Multiple dependent claim
109	80	209	40	Reissue independent claims over original patent
110	22	210	11	Reissue claims in excess of 20 and over original patent

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FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)		Fee
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for reexamination	
112	*920	112	*920	Requesting publication of SIR prior to Examiner action	
113	*1,840	113	*1,840	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for response within first month	
116	400	216	200	Extension for response within second month	
117	950	217	475	Extension for response within third month	
118	1,510	218	755	Extension for response within fourth month	
119	310	219	155	Notice of Appeal	
120	310	220	155	Filing a brief in support of an appeal	
121	270	221	135	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive unavoidably abandoned application	
141	1,320	241	660	Petition to revive unintentionally abandoned application	
142	1,320	242	660	Utility issue fee (or reissue)	
143	450	243	225	Design issue fee	
144	670	244	335	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	40.00
146	790	246	395	Filing a submission after final rejection (37 CFR 1.129(a))	
149	790	249	395	For each additional invention to be examined (37 CFR 1.129(b))	

Other fee (specify) _____

Other fee (specify) _____

SUBTOTAL (3) ($)40.00

* Reduced by Basic Filing Fee Paid

SUBMITTED BY				Complete (if applicable)	
Typed or Printed Name	Barry E. Sammons			Reg. Number	25,608
Signature	Barry E. Sammons	Date	Oct 16, 1997	Deposit Account User ID	17-0055

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ACOUSTIC FORCE GENERATION BY AMPLITUDE MODULATING A SONIC BEAM

Statement Regarding Federally Sponsored Research

This invention was made with United States Government support awarded by the National Institute of Health (NIH) Grant No.: CA43920. The United States Government has certain rights in this invention.

Background Of The Invention

The field of the invention is the detection and imaging of objects using acoustic beams.

In the field of medical imaging there are a number of modes in which ultrasound can be used to produce images of objects within a patient. The ultrasound transmitter may be placed on one side of the object and the sound transmitted through the object to the ultrasound receiver placed on the other side ("transmission" mode). With transmission mode methods, an image may be produced in which the brightness of each image pixel is a function of the amplitude of the ultrasound that reaches the receiver ("attenuation mode"), or the brightness of each pixel is a function of the time required for the sound to reach the receiver ("time-of-flight" or "speed of sound" mode). In the alternative, the receiver may be positioned on the same side of the object as the transmitter and an image may be produced in which the brightness of each pixel is a function of the amplitude of the ultrasound reflected from the object back to the receiver ("reflection", "backscatter" or "echo" mode). In another mode of operation ("Doppler" mode) the movement of the object is detected and imaged by measuring the phase of the ultrasound reflected from the object back to the receiver.

In all of these medical imaging applications ultrasonic waves are transmitted and ultrasonic waves are received. The higher sonic frequencies enable precise beams to be formed in both the transmit and receive modes. Ultrasonic transducers for medical applications are constructed from one or more piezoelectric elements sandwiched between a pair of electrodes. Such piezoelectric elements are typically constructed of lead zirconate titanate (PZT), polyvinylidene diflouride (PVDF), or PZT ceramic/polymer composite. The electrodes are connected to a voltage source, and when a voltage waveform is applied, the piezoelectric elements change in size at a frequency corresponding to that of the applied voltage. When a voltage waveform is applied, the piezoelectric elements emits an ultrasonic wave into the media to which it is coupled at the frequencies contained in the excitation waveform. Conversely, when an ultrasonic wave strikes the piezoelectric element, the element produces a corresponding voltage across its electrodes. A number of such ultrasonic transducer constructions are disclosed in U.S. Patent Nos. 4,217,684; 4,425,525; 4,441,503; 4,470,305 and 4,569,231.

When used for ultrasonic imaging, the transducer typically has a number of piezoelectric elements arranged in an array and driven with separate voltages (apodizing). By controlling the time delay (or phase) and amplitude of the applied voltages, the ultrasonic waves produced by the piezoelectric elements (transmission mode) combine to produce a net ultrasonic wave that travels along a preferred beam direction and is focused at a selected point along the beam. By controlling the time delay and amplitude of the applied voltages, the beam with its focal point can be moved in a plane to scan the subject. A number of such ultrasonic imaging systems are described in U.S. Patent Nos. 4,155,258; 4,155,260; 4,154,113; 4,155,259; 4,180,790;

4,470,303; 4,662,223; 4,669,314; 4,809,184; 5,081,995 and 5,492,121.

The acoustic radiation force exerted by an acoustic wave on an object in its path is a universal phenomenon common to all forms of radiated energy. When a beam of light is absorbed or reflected by a surface, a small force is exerted on that surface. The same is true for electromagnetic waves, transverse waves on an elastic string, and surface waves on a liquid. This force is produced by a "radiated pressure" and a complete disclosure of this phenomenon is set forth by G.R. Torr, "The Acoustic Radiation Force", Am. J. Phys. 52(5), May 1984.

The measurement of radiation force exerted by sound waves has become important in recent years to determine the power outputs of medical imaging ultrasonic transducers, Beissner, K., "Measurement Techniques In Ultrasonic Exposimetry," eds. M.C. Ziskin and P.A. Lewin, CRC Press, Boca Raton, 1993. The transducer is submerged in a tank of water and the ultrasonic beam is directed towards an absorbing or reflecting target in the tank. An absorbing target may be realized by a slab of natural rubber, or a reflecting target by an air-backed thin metal plate. If the ultrasonic beam is directed horizontally, the force can be determined by suspending the target as a pendulum and measuring its deflection. The measurements are made in water because the characteristic acoustic impedances of water and human soft tissue are similar, thus the measured ultrasonic beam power is virtually equal to the power radiated by the transducer into the human body provided that the effect of tissue loss has been accounted for.

It is generally accepted that the radiation force F exerted on a totally absorbing target by an ultrasonic beam of power P is given by the equation

$$F = P/c,$$

where c is the speed of sound in the medium surrounding the target. For normal incidence on a plane reflecting surface the radiation force has twice this value. The speed of sound in water is 1500m/s, thus the radiation force on an absorbing target in water is about 6.67×10^{-4} newtons/watt.

This sonic radiation force has found application in medicine in the field of extracorporeal shock wave lithotripsy. By applying a set of powerful acoustic shock waves at the surface of the patient such that their energies focus on a target inside the patient, objects such as renal or gall-stones can be fragmented. Such lithotripsy systems are described, for example, in Goldstein, A., "Sources of Ultrasonic Exposure," Ultrasonic Exposimetry, eds. M.C. Ziskin and P.A. Lewin, CRC Press, Boca Raton, 1993.

Another application which employs an ultrasonic radiation force produced by a transducer is disclosed by Sugimoto et al, "Tissue Hardness Measurement Using The Radiation Force Of Focused Ultrasound", IEEE Ultrasonics Symposium , pp. 1377-80, 1990. In this experiment, a pulse of focused ultrasonic radiation is applied to deform the object which is positioned at the focal point of the transducer. The deformation is measured using a separate pulse-echo ultrasonic system and the hardness of the deformed object is measured. Measurements are made based on the rate of object deformation as the acoustic force is continuously applied, or by the rate of relaxation of the deformation after the force is removed.

A similar system is disclosed by T. Sato, et al. "Imaging of Acoustical Nonlinear Parameters and Its Medical and Industrial Applications: A Viewpoint as Generalized Percussion", Acoustical Imaging, Vol. 20, pg 9-18, published in 1993 by Plenum Press. In this system a lower frequency wave (350 kHz) is produced to act as a percussion force, and an ultrasonic wave (5 MHz) is used

in a pulse echo mode to produce an image of the subject. The percussion force is said to perturb second order nonlinear interactions in tissues, which reveal more structural information than the conventional ultrasonic pulse/echo system alone.

Summary Of The Invention

The present invention is a method and system for producing an acoustic radiation force at a target location by directing a high frequency sound beam at the location. The high frequency sound beam is amplitude modulated and a radiation force is produced at the location which varies in accordance with the amplitude modulation.

A general object of the invention is to detect or characterize an object based on its mechanical properties. An object at the location of the beam will respond to the applied acoustic radiation force by producing an acoustic wave that can be detected with a microphone or other detection apparatus. The detected acoustic wave may be used to detect the presence of the object or it may be used to detect and evaluate the mechanical properties of the object.

Another object of the invention is to produce an image of the target object. The high frequency sound beam may be moved to scan the object and signals indicative of the acoustic wave produced at each scanned location may be acquired. The acquired signals are used to produce an image of the object.

Another object of the invention is to project a force into an object to measure the object's mechanical characteristics. The radiation force produced by the high frequency sound beam produces motion at the location which can be detected and analyzed to measure the mechanical characteristics at that location. Detection

can be performed in a number of ways, including Doppler ultrasound and nuclear magnetic resonance imaging.

Yet another object of the invention is to regenerate baseband audio at a remote location. By modulating the high frequency sound beam with a baseband audio signal, the radiation force at the location will vary as a function of the baseband audio signal and a corresponding acoustic wave is produced. By using the highly directional high frequency sound beam, therefore, a non-directional audio wave can be precisely produced at the location.

The foregoing and other objects and advantages of the invention will appear from the following description. In the description, reference is made to the accompanying drawings which form a part hereof, and in which there is shown by way of illustration a preferred embodiment of the invention. Such embodiment does not necessarily represent the full scope of the invention, however, and reference is made therefore to the claims herein for interpreting the scope of the invention.

Brief Description Of The Drawings

Fig. 1 is a block diagram of a first embodiment of the invention used to detect the presence of an object according to the present invention;

Fig. 2 is a block diagram of a second embodiment of the invention used to image an object according to the present invention; and

Fig. 3 is a block diagram of a third embodiment of the invention used to convey a signal acoustically to a distant target object according to the present invention.

General Description Of The Invention

Consider an ultrasonic source directing its beam on a large target in water. The radiation force, F, for the plane wave case is commonly written as

$$F = KP/c, \quad (1)$$

where P, c, and K are the time averaged acoustic power, sound speed in water, and a constant, respectively. The value of K for a perfectly absorbing target is 1, and for a perfectly reflecting target it is 2. For a focused beam impinging on a partially reflecting target of arbitrary size, the linear relation of (1) still holds, however, the value of K is different and can be determined as a function of target power reflection coefficient and its size as described by J.Wu, "Calculation of Acoustic Radiation Force Generated by Focused Beams Using the Ray Acoustic Approach," J. Acoust. Soc. Am. 97(5), pt. 1, May 1995.

In the present invention the high frequency field is generated by a single, ultrasonic source (single element or array of elements) driven by an amplitude modulated signal. The carrier frequency is ω_0 and the modulating signal, h(t), is defined as:

$$h(t)=\sqrt{u(t)}, \quad (2)$$

where

$$u(t)=1+f(t). \quad (3)$$

The signal f(t) is a low frequency signal. We assume $|f(t)|<1$, also we assume that the bandwidth of f(t) is much less than the carrier frequency ω_0.

We assume the beam is propagating along the z-axis. The field on the z=0 plane can be written as

$$s(t)=g(x,y)h(t)\cos(\omega_0 t), \quad (4)$$

where g(x,y) is the beam profile on the z=0 plane. It can be shown that the acoustic power density has slow

variations about its long time average. Denoting this component by $P_1(t,x,y)$, we can write

$$P_1(t,x,y)=\frac{1}{2}g^2(x,y)h^2(t)\,. \tag{5}$$

Assuming a target is present at z=0 plane, then referring to Equation (1), the radiation force exerted on this target by $P_1(t,x,y)$ may be found by the following integration:

$$F_1(t)=\frac{K}{c}\int\int P_1(t,x,y)dxdy\,. \tag{6}$$

The result of this integration is a function proportional to $h^2(t) = 1+f(t)$. The time-varying component of this force vibrates the target proportional to the signal f(t). The target displacement due to this force, r(t), may be written as

$$r(t)=\frac{1}{2}K'f(t) \tag{7}$$

where K' is a constant whose value depends on size, power reflection coefficient, and other mechanical parameters of the target, such as mass and damping factors, that determine its response to a given force.

Within the target area the force indicated by Equation (6) will be applied to the object. The manner in which the object responds to this force will, of course, depend on its mechanical characteristics. As the embodiments of the invention described below will indicate, there are many uses for this invention which stem from its ability to accurately project a low frequency acoustic force to a defined area.

The response of an object to the radiation force may be explained by considering a simplified, one-dimensional equation of motion for the mass-spring model. In this model, we assume a mass m is held by a spring having a "stiffness constant" of μ. We also assume that motion of this mass is damped by friction or by other mechanisms represented by the "resistance constant" R_m. Now consider a sinusoidal force $F_1(t)=A\cos\omega_m t$ being applied to this mass. As described by P.M. Morse and K.V. Ingard, "Theoretical Acoustics," McGraw Hill, 1968, the steady-state motion of the mass due to this force can be written as:

$$x(t)=A\ \cos\ (\omega_m t+\phi)/\omega_m|Z_m|$$

where

$$Z_m = R_m - j\ (\omega_m-\mu/\omega_m)$$

is the mechanical impedance, and

$$\tan\phi = (\omega_m-\mu/\omega_m)/R_m$$

Thus the amplitude and phase of the displacement of the mass are determined by the mechanical properties m, R_m and μ. At its resonant frequency, where $\omega_m=\sqrt{\mu/m}$, the amplitude of the motion reaches its maximum value.

Description Of The Preferred Embodiment

Referring particularly to Fig. 1, a first embodiment of the invention is used to detect the presence of an object based upon the acoustic wave produced by the object in response to the applied force $F_1(t)$. This detector system includes an ultrasonic transducer 10 which produces a focused beam 14 of beamwidth w = 2mm at

its focal point. The transducer 10 is driven by an RF generator 18 that produces an ultrasonic frequency $\omega_0 = 2\pi$ x 3,500,000 rad./sec. This carrier signal ω_0 is applied to an amplitude modulator 19 which also receives the modulating signal h(t). Here we assume $f(t)=\cos\omega_m t$, where $\omega_m << \omega_0$. The modulated carrier is amplified in power amplifier 20 and applied to the transducer 10.

The acoustic field produced by the object 21 in response to the force produced by the focused beam 14 is received by a hydrophone 22. The received signal is applied through a band-pass filter 24 to an audio amplifier 26. The band-pass filter 24 has a narrow pass band centered on ω_m to reject noise and any reflected ultrasonic signals. The amplified audio signal may be applied to a loudspeaker 28 or an earphone to provide the operator with an indication of the amplitude of the acoustic wave produced by the object 21. The transducer 10 can be moved physically to scan the object 21, or in the alternative the beam 14 can be steered electronically to scan the object 21. An alternative choice for h(t) can be, for example, $h(t)=\cos\omega_m t$. In this case, the acoustic field produced by the object is proportional to the $\cos 2\omega_m t$. In this case the band pass filter 24 must be centered around $2\omega_m$.

A second embodiment of the invention is a novel imaging system. Rather than relying on the reflection or attenuation of an ultrasonic wave by the object as is done in ultrasound imagers, the imager of the present invention relies on other mechanical properties of the object. More specifically, the ability of the object to convert the force $F_1(t)$ to an acoustic wave that can be detected by the receiver.

Referring particularly to Fig. 2, the imaging system includes a focused transducer 30 which produces a beam 38 which has a focal region from 6 cm to 13 cm, and a beamwidth of w=2mm (defined as the full-width at half-

maximum). The transducer 30 is driven by an RF generator 32 which produces a carrier signal $\omega_0=2\pi$ x 3,500,000 rad./sec. The carrier signal ω_0 is amplitude modulated at 34 by a modulating signal h(t), and the modulated carrier is amplified by power amplifier 36.

The sonic wave produced by the target object 42 in response to the force $F_1(t)$ is received by a hydrophone 44 and digitized. The receiver signal is filtered by a band-pass filter 46 centered on the frequency of the signal h(t), amplified at audio amplifier 48 and digitized by a 12-bit analog-to-digital converter 50 at 100,000 samples/sec. The processor 52 calculates the mean amplitude (or the standard deviation) and/or phase of 600 samples of the digitized signal, then stores this value in the image array 54 at a location corresponding to the position of the focal spot of beam 38. Processor 52 also controls other parts of the system to carry out the scan process. It steers the beam 38 to raster scan the object 42 in the x-y (or x-z) plane. Beam steering is accomplished either mechanically using two stepper motors (not shown), or by well known phased array techniques. Processor 52 also provides the trigger signals needed to synchronize the scanning and digitization function. The resulting image produced after a complete raster scan may be enhanced using known image enhancement methods and/or displayed on a monitor 56. A two-dimensional image is thus produced in which the gray scale intensity of each pixel indicates the acoustic level and/or phase produced by the target 42 in response to the applied force $F_1(t)$.

A variation of this two-dimensional imaging system can be used to acquire a three-dimensional image in which two dimensions are spatial (x,z) and the third dimension is modulation frequency amplitude. In this alternative, the signal f(t) is swept through a range of modulation frequencies. The acquired signal samples at each x,z

beam location are stored at successive frequency bins in the image array 54. The resulting frequency dimension provides the information needed for analyzing the spectrum of the object's acoustic response to mechanical stimulations at different frequencies.

As an example application, one can make use of this method to identify calcification in tissue and estimate its thickness and size. Referring to the mass-spring model described above, the amplitude of the motion peaks at the resonant frequency, and this is proportional to $1/\sqrt{m}$. Calcification with different thicknesses have different masses, thus resonating at different frequencies. Hence, when examining different regions of calcification by the variable modulation frequency method, one can expect to see peaks at different frequency bins depending on the thickness and size of the calcification.

Other imaging modalities can also be used to measure the motion resulting from the radiation force produced by the present invention. For example, a magnetic resonance imaging ("MRI") system, such as that described in co-pending U.S. patent application serial no. 325,834 filed October 19, 1994 and entitled "*MR Imaging Of Synchronous Spin Motions And Strain Waves*" can be used to image the mechanical characteristics of the scanned object. In this system a motion sensitizing magnetic field gradient on the MRI system is synchronized with the applied radiation force (i.e. the signal f(t)) and the resulting motion is precisely indicated by the phase of the acquired NMR signals. As described in this co-pending application which is incorporated herein by reference, nearly all mechanical properties of the imaged object can be measured and used to modulate the intensity of a reconstructed image. This method can be used to provide a map of tissue stiffness which is an excellent tool to

detect deep tumors. Again, an alternative choice for $h(t)$ is $h(t)=\cos\omega_m t$ in which case the acoustic field is proportional to $\cos 2\omega_m t$. In this case the band pass filter is centered around $2\omega_m$ rather than ω_m.

A third embodiment of the invention serves an entirely different function than those described above. Rather than obtaining an indication of the presence or nature of a target object, in the third embodiment of the invention information is transferred to the target object in the form of acoustical energy. By using an ultrasonic beam which can be finely focused and directed, this transfer of information can be precisely targeted.

Referring particularly to Fig. 3, the audio regeneration system includes an ultrasound transducer 80 that produces a beam 84 which focuses on a target object 88. The beam width at its focal point is w=2mm. The transducer 80 is driven by an RF generator 90 which produces a high frequency carrier signal ω_0 at a frequency of 3.5 MHz. The carrier signal ω_0 is applied to an amplitude modulator 96 which also receives a modulating signal $h(t)$. The output of the modulator 96 $(h(t)\cos(\omega_0 t))$ is applied through a power amplifier 94 to the transducer 80.

The modulating signal $h(t)$ is produced by a square root circuit 98. It receives as its input the baseband signal $f(t)$ plus "1". The baseband signal $f(t)$ is less than "1".

The ultrasonic beam 84 causes the target object 88 to vibrate in response to the baseband signal $f(t)$. The beam 84 is made very directive because the wavelength of the ultrasound beam at carrier frequency ω_0 is very small compared to that of the baseband signal $f(t)$. The target 88 acts as the converter of the high frequency ultrasound energy to the baseband frequency energy and the frequency response can be made very flat because the bandwidth of

the baseband signal f(t) is very small relative to the ultrasound carrier frequency ω_0.

One medical application of this embodiment of the invention is a hearing aid. The transducer is positioned along side the user's temple and the ultrasonic beam is directed to structures in the inner ear. The baseband signal f(t) is the ambient sound picked up by a microphone and amplified. This ambient sound is reproduced in the inner ear by vibrating structures in the inner ear. The eardrum and the middle ear are completely by-passed by this sound regeneration system, and patients with hearing loss due to problems in these structures can be helped.

While in many medical applications the transducer is positioned outside the patient and directs ultrasound into an object in the patient, it is also possible to place the transducer inside the patient. For example, the transducer may be mounted on the end of a catheter as described, for example, in U.S. patent No. 5,345,940 and inserted into the patient through the vascular system. This enables the transducer to be positioned closer to the target object.

The invention can be used to remotely measure the elastic constants of a material. For example, a swept frequency force can be applied to a metallic rod to measure its resonant frequency. The resonant frequency can be used to accurately measure the Young's modulus of the rod material.

The invention can also be used for accurate and remote measurement of the sheer viscosity, or the density, of a liquid. This can be done by aiming the ultrasound beam on a well characterized tuning fork immersed in the liquid. The sheer viscosity or the density can be measured accurately and remotely by measuring the shift in the resonant frequency of the

tuning fork with respect to its natural resonant frequency in vacuum.

Claims

1. A detector system for indicating the presence of an object, the combination comprising:

a sonic beam producer for producing a sonic beam at a high frequency ω_0 which is directed at the object;

an amplitude modulator for supplying a signal to the sonic beam producer at the high frequency ω_0 which is modulated in amplitude at a modulation frequency; and

a detector for receiving a sonic wave produced at the modulation frequency by the object and the detector having means for indicating the presence of the object in response to the received sonic wave.

2. The detector system as recited in claim 1 in which the modulation frequency is within the audible hearing range of humans and the detector indicates its presence by producing an audible sound.

3. The detector system as recited in claim 1 in which the modulation frequency is swept through a range of frequencies such that the frequency of the sonic wave is also swept through a range of frequencies.

4. The detector system as recited in claim 1 in which the object is located within a human subject and the sonic beam producer and the detector are located outside the human subject.

5. A detector system for indicating the mechanical characteristics of an object, the combination comprising:

a sonic beam producer for producing a sonic beam at a high frequency ω_0 which is directed at the object;

an amplitude modulator for supplying a signal to the sonic beam producer at the high frequency ω_0 which is modulated in amplitude to produce a force in the object corresponding to the modulating signal; and

means for detecting motion in the object caused by the force.

6. The detector system as recited in claim 5 in which the means for detecting is an ultrasonic Doppler system.

7. The detector system as recited in claim 5 in which the means for detecting is a nuclear magnetic resonance system.

8. The detector system as recited in claim 5 in which the frequency of the modulating signal is varied over a range of frequencies such that the frequency of the force is also varied over a range of frequencies.

9. The detector system as recited in claim 5 in which the object is located within a human subject and the sonic beam producer and the means for detecting are located outside the human subject.

10. An imaging system which comprises:

a sonic beam producer for producing a sonic beam at a high frequency ω_0 which is directed at the object to be imaged;

an amplitude modulator for supplying a signal to the sonic producer at the high frequency ω_0 which is modulated in amplitude at a modulation frequency;

means for moving the sonic beam to scan its focal point over a region in the object to be imaged;

a detector for receiving a sonic wave produced at the modulating frequency by the object as it is scanned and producing an output signal indicative of the amplitude of the sonic wave; and

a display for receiving the output signal and producing an image indicative of the amplitude of the sonic wave emanating from locations in said region.

11. The imaging system as recited in claim 10 in which the object is located within a human subject and the imaging system is located outside the human subject.

12. The imaging system as recited in claim 10 in which the modulating frequency is changed over a range of values as the focal point scans the region to be imaged, and the detector receives the sonic waves produced at the corresponding frequencies.

13. A regeneration system for projecting an audio signal to a location in an object, the combination comprising:

a sonic beam producer for producing a high frequency sonic beam that passes into the object and to the location; and

an amplitude modulator for supplying a signal to the sonic beam producer at the high frequency which is modulated in amplitude with the audio signal;

whereby the modulated sonic beam produces a force on the object at the location that varies as a function of the audio signal, and whereby said force reproduces the audio signal through vibration of said object.

14. The regeneration system as recited in claim 13 in which the object is an animal.

15. The regeneration system as recited in claim 13 in which the object is a body of water.

16. The regeneration system as recited in claim 13 in which the object is a room and the sonic beam passes through air in the room.

Abstract Of The Disclosure

A force is produced within an object by an ultrasonic beam. The frequency of this force is equal to the frequency of a signal used to modulated the amplitude of the beam. The sonic waves produced by the object in response to the force can be used to detect the presence of objects or to image objects based on their mechanical properties. It can also be used to regenerate a desired audio signal in the object.

qb2\263937

FIG. 1

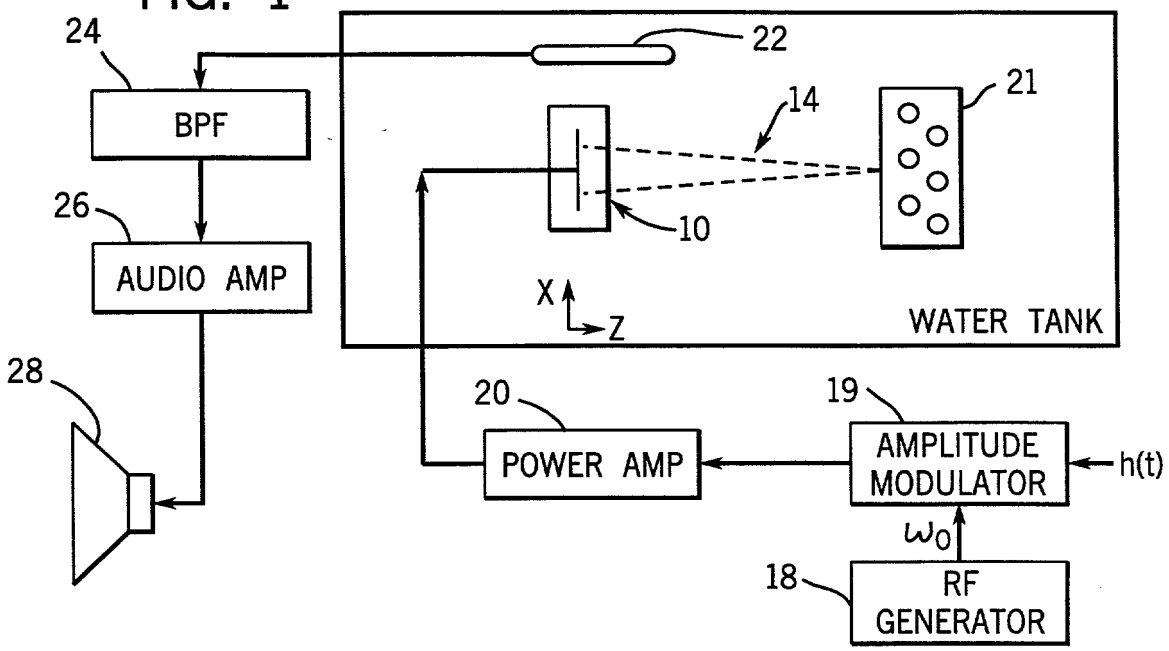

24
BPF
26
AUDIO AMP
28
22
14
21
10
X
Z
WATER TANK
20
POWER AMP
19
AMPLITUDE MODULATOR
h(t)
ω_0
18
RF GENERATOR

FIG. 2

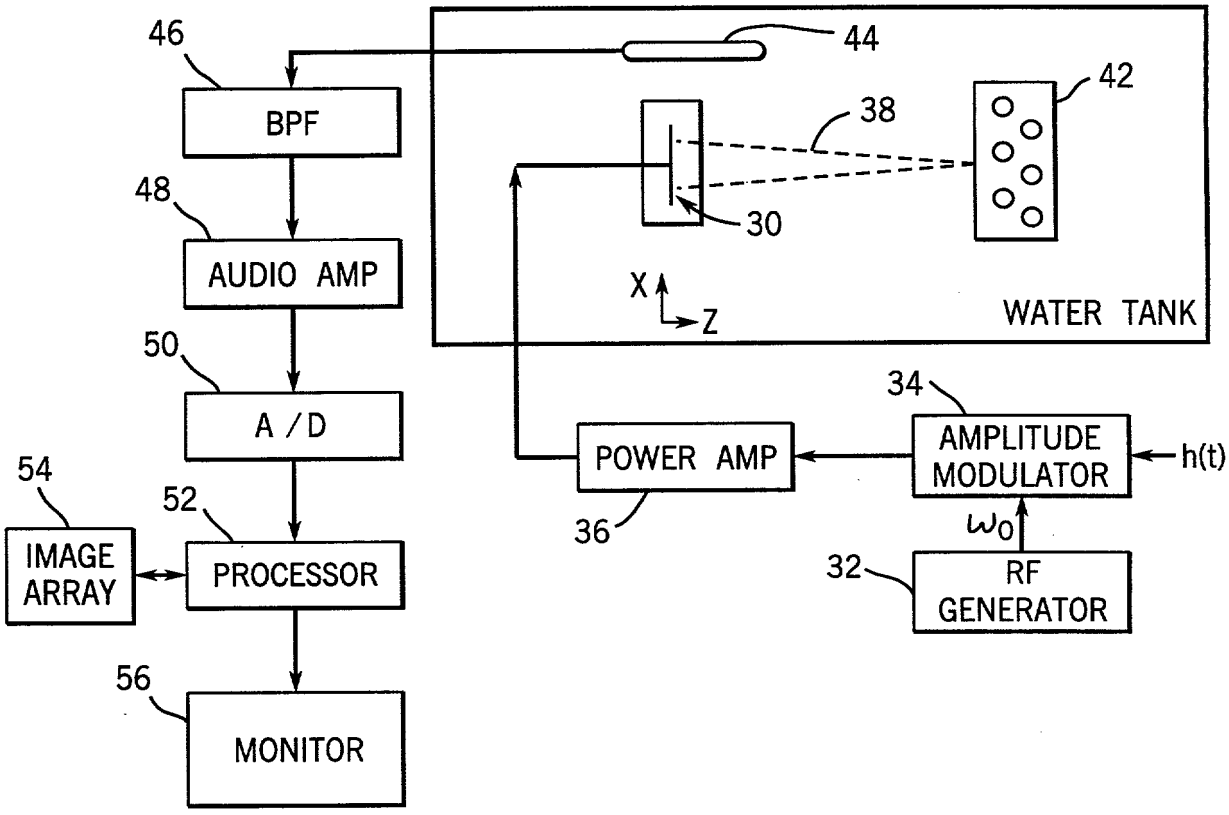
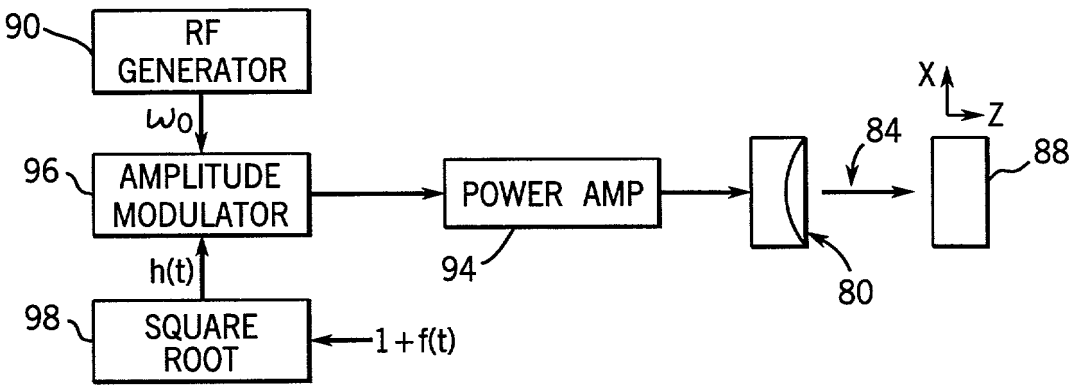

46
BPF
48
AUDIO AMP
50
A / D
54
IMAGE ARRAY
52
PROCESSOR
56
MONITOR
44
42
38
30
X
Z
WATER TANK
34
POWER AMP
AMPLITUDE MODULATOR
h(t)
36
ω_0
32
RF GENERATOR

FIG. 3


90
RF GENERATOR
ωo
96
AMPLITUDE MODULATOR
h(t)
98
SQUARE ROOT
1+f(t)
POWER AMP
94
X
Z
84
88
80

EXPRESS MAIL LABEL NO. EI 958 698 639 US

PTO/SB/01 (6-95)
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DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION

[X] Declaration Submitted with Initial Filing OR [ ] Declaration Submitted after Initial Filing

Attorney Docket Number	630666.90245
First Named Inventor	Greenleaf, James F.
COMPLETE IF KNOWN	
Application Number	
Filing Date	
Group Art Unit	
Examiner Name	

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe that I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

ACOUSTIC FORCE GENERATION BY AMPLITUDE MODULATING A SONIC BEAM

(Title of the Invention)

the specification of which

[X] is attached hereto

OR

[ ] was filed on (MM/DD/YYYY) _____ as United States Application Number or PCT International Application Number _____ and was amended on (MM/DD/YYYY) _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code §119(a)-(d) or §365(b) of any foreign application(s) for patent or inventor's certificate or §365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached? YES	NO
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]

[ ] Additional foreign applications numbers are listed on a supplemental priority sheet attached hereto:

I hereby claim the benefit under Title 35, United States Code §119(e) of any United States provisional application(s) listed below.

Application Number(s)	Filing Date (MM/DD/YYYY)	
60/032,123	12/05/96	[ ] Additional provisional application numbers are listed on a supplemental priority sheet attached hereto.

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I hereby claim benefit under Title 35, United States Code §120 of any United States application(s), or §365(C) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application or PCT international application in the manner provided in the first paragraph of Title 35, United States Code §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. Parent Application Number	PCT Parent Number	Parent Filing Date (MM/DD/YYYY)	Parent Patent Number *(if applicable)*

[ ] Additional U.S. or PCT international application numbers are listed on a supplemental priority sheet attached hereto

As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and all continuation and divisional applications based thereon, and to transact all business in the Patent and Trademark Office connected therewith:

[ ] Firm Name _____ Customer Number or label _____

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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DECLARATION

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Post Office:

City	State	Zip	Country	Applicant Authority

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Inventor's Signature: Date:

Residence:	State	Country	Citizenship
	WI		

Post Office:

Post Office:

City	State	Zip	Country	Applicant Authority

Name of Additional Joint Inventor, if any: | A petition has been filed for this unsigned inventor

Given	Middle			Suffix

Inventor's Signature: Date:

Residence:	State	Country	Citizenship
	WI		

Post Office:

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City	State	Zip	Country	Applicant Authority

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